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SOME HOST PLANTS OF CURLY TOP

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INTRODUCTION

Sugar-beet curly top, transmitted by the beet leafhopper, *Eutettix tenellus* (Baker), affects many species of plants among both cultivated plants and weeds. In years when a disastrous outbreak of curly top occurs among sugar beets in the western part of the United States, other cultivated plants are seriously damaged by the disease.

Forty thousand acres of beets were planted in the San Joaquin Valley during the season of 1918–19. Thirty thousand acres affected with curly top were plowed under or were not worth harvesting, and the beet leafhoppers were thus forced to seek other food plants.

During 1919, cantaloupes were a failure in the San Joaquin Valley. There was no evidence of a root rot, although root knots caused by the garden nematode, *Heterodera radicola*, were found on some of the plants examined. The trouble was attributed to a cold spring followed by warm weather, to the use of cold irrigation water, and later to a shortage of water. During the past two years cantaloupes were found to be naturally infected with curly top in the Salinas Valley and the symptoms resembled those observed in the San Joaquin Valley during 1919.

Spinach was found to be naturally infected with curly top in the San Joaquin Valley in 1919, and in many other localities in later years.

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During 1924, Carsner[3, 4] came to the conclusion, on circumstantial evidence, that beans were naturally infected with curly top in Idaho. The experiments reported in this paper have demonstrated that a large number of field and garden beans growing in California are naturally infected with and susceptible to the disease.

During 1925 and 1926, curly top was transmitted to sugar beets from many varieties of squashes and pumpkins naturally infected in the field in California. The transfer of curly top from squashes and pumpkins which had been experimentally inoculated with curly top by infected beet leafhoppers, and which showed typical symptoms, back to sugar beets was also accomplished.

McKay and Dykstra[5] made a comparison of the symptoms of squash infected with the beet leafhopper with symptoms observed in the field and "circumstantial evidence suggested that the disease was due to the virus of sugar-beet curly top." The general failure of squash in the Northwest during 1926 was due largely to this disease.

An investigation was undertaken to determine what economic plants and weeds are naturally infected with the disease. Experiments were also conducted in the greenhouse to ascertain what varieties of cultivated plants are immune, resistant, and susceptible to curly top. A list of cultivated plants immune to the disease will appear in a future paper. A study of the symptoms of the disease in varieties experimentally infected was made so that naturally infected plants could be recognized in the field. The longevity of the adult leafhopper was determined and also the cultivated plants on which their life history could be completed. Observations were made on the relation of the infection of cultivated plants to the spring dispersal, migrations, autumn dispersal, and flights of the insects occurring with the plowing under of badly diseased sugar beets. This paper gives the results of curly-top investigations concerning economic plants and weeds of the families Chenopodiaceae, Leguminosae, and Cucurbitaceae. The work has been extended to other families and the data will appear in future publications.

METHODS OF TESTING PLANTS NATURALLY INFECTED WITH CURLY TOP

Several methods were used in determining whether economic plants and weeds were naturally infected with curly top. In the early work[6, 7] began in 1918, cultivated plants and weeds on which the beet leafhoppers were found were removed from the field and enclosed in cages in the greenhouse. Nymphs which hatched from

eggs deposited in the plants under natural conditions were fed in cages on the plants. As these plants usually became dry in the cages in from one to two weeks, several potted sugar beets were put into the cages to allow the nymphs to complete their life cycle. If the plants were infected with curly top under natural conditions, the nymphs transmitted the disease from the plants to the beets. This method had a twofold function: to determine, first the natural host plants of the beet leafhopper; and second, the cultivated plants and weeds which were naturally infected with curly top.

A simple method was adopted later in testing naturally infected plants. Male beet leafhoppers non-infective as to curly top were fed on stunted diseased plants removed from the field, and then transferred to healthy beet seedlings. Males were used rather than females so as to avoid egg deposition. If the beets developed curly top it was evident that the cultivated plants and weeds had been naturally infected with the disease. In each case the number of non-infective males which fed on a plant suspected of harboring curly top varied from ten to twenty-five or more. A high mortality of the insects often occurred in the greenhouse owing to unfavorable food. The hoppers were transferred, according to their death rate, to two or more beets. For instance, when twenty-five males were used and some died, the remainder were equally divided between two cages, each enclosing a beet. If the symptoms of curly top failed to develop in from one to two weeks the beets were examined daily in insect-proof chambers for a period of six weeks. Checks were often used in which apparently healthy cultivated plants or weeds were removed from the field, and cross inoculations were made with non-infective leafhoppers feeding on the plants, to beet seedlings.

METHODS OF EXPERIMENTALLY INFECTING PLANTS WITH CURLY TOP

A large number of cultivated plants and weeds were experimentally infected with curly top so that the symptoms of naturally infected plants could be recognized in the field. The plants were grown from seeds in a greenhouse which was fumigated twice a month with nicotine sulphate. From two to ten infective male beet leafhoppers confined in cages were used to inoculate the plants, the number depending upon the size of the plant. When the longevity of the adults was short because of unfavorable food, the plants were repeatedly inoculated with different lots of males. The period allowed

for inoculation was usually two weeks, or less, if symptoms of curly top developed earlier. After the period of inoculation, the cage containing the infective males was removed from the plant. In another cage non-infective males were fed on the inoculated plant, for a period of at least two or three days, or longer if the food material was favorable. The leafhoppers were then transferred from the inoculated plant to healthy beet seedlings. If the beet developed curly top, it was evident that the inoculated plant had been infected with the disease.

FLIGHTS OF BEET LEAFHOPPER

Spring Dispersal.—After the pasture vegetation becomes dry on the plains and foothills of a natural breeding ground, the spring-brood females fly into the adjacent cultivated areas. Most of the males remain behind on the plains and foothills and die. The invasion is not a single flight. The insects invade the cultivated regions in the San Joaquin Valley during a period of from four to ten weeks.

Spring Migration.—The appearance of the beet leafhoppers in the Sacramento Valley seems to be associated with a spring migration, probaby a northward movement from the San Joaquin Valley. The evidence for a spring migration hinges on the fact that from 1918 to 1928 the insects did not invade the cultivated areas until some time after the pasture vegetation became dry on the foothills of the Coast Range.

Flights Associated with Unfavorable Food.—Flights of the beet leafhoppers occur in the cultivated areas when the food material becomes unfavorable. When the outer leaves of badly diseased beets become sun-scorched during hot weather, and the remaining tuft of diseased leaves become thick and leathery, many of the summer-brood adults seek other food and breeding plants. The insects will also desert badly diseased weeds. The hoppers will leave large beets with dense foliage covering the rows, and fly to more favorable host plants, often to smaller beets in the vicinity. When certain species of annual saltbushes become woody in July, a dissemination of the leafhoppers to other plants occurs. In the struggle for food of the ever-increasing hordes of bugs during the summer, random flights occur, and in all probability some of the insects fly into fields of other crops and transmit curly top.

Autumn Dispersal.—During October and November the overwintering adults fly from the cultivated areas of the San Joaquin Valley to the plains and foothills. In the Salinas Valley the leaf-

hoppers fly to the foothills, following the Salinas River and its tributaries.

Plains and Foothill Breeding Areas.—The foothill breeding area of the beet leafhopper in the San Joaquin Valley extends from Mt. Diablo to the Tehachapi Mountains on the Coast Range, also the foothills of the Tehachapi and Sierra Nevada Mountains as far north as Round Valley near Lindsay. The natural breeding grounds also include the plains of the middle San Joaquin Valley and most of Kern County in the southern section of the valley.

During years with early autumn rains, the beet leafhoppers were taken on the foothills of the Coast Range bounding the Sacramento Valley, but during the winter the hoppers were exterminated. No hold-over bugs were taken in the early-planted beet fields nor was a single case of curly top observed until after the migratory flights occurred. In all probability, the factors which exterminate the overwintering adults in the Sacramento Valley are heavy fogs and rainfall. The normal rainfall in this valley varies from 19.28 to 27.75 inches. The hot dry summers in the Sacramento Valley are favorable to the immigrants and later generations in the cultivated areas.

CHENOPODIACEAE, GOOSEFOOT OR SALTBUSH FAMILY

CURLY-TOP SYMPTOMS ON THE SUGAR BEET (BETA VULGARIS)

Reliable and constant symptoms of sugar-beet curly top are not always present in all cultivated plants and weeds and hence all visible symptoms of beet curly top will be described as a basis for comparison with the characteristics of the disease in other plants.

Leaf Curling.—The earliest symptoms of curly top to appear in most diseased beets is an inward rolling of the lower and outer margin of the youngest leaves. Later the entire blade may show a pronounced inward curling toward the mid-rib (figs. 1 and 2). There is a considerable variation as to the number of curled leaves occurring in older diseased beets, but very often the outer full-grown leaves do not show this character. A beet showing curly leaves and no other symptoms of the disease is not always a curly-top beet, for perfectly healthy beets may show the same characteristic.

The foliage of some diseased beets shows an outward rolling of the margin of the leaves and an outward puckering of the blade between the veins. Sometimes the two types of leaf curl are combined, the blade curling outward and the margin inward.

Fig. 1. Side view of sugar beet (*Beta vulgaris*) affected with curly top, showing inward curling of leaves toward the mid-rib.

Fig. 2. Top view of same beet as that shown in figure 1, showing inward curl of leaves.

Blister-like Elevations.—A symptom of curly top which sometimes develops on the leaves of beet seedlings is small blister-like elevations (pl. 1, figs. 1, 2). In beet seedlings with four to six leaves including the cotyledons, these blisters may appear simultaneously on the outer and the inner leaves, or on an outer leaf before the youngest leaf is developed, or on only the youngest leaf. The blister-like elevations sometimes develop in two days after the beet seedling is infected with the disease.

Transparent Venation.—A reliable and constant symptom of curly top plainly visible to the eye is the transparent network of minute veins (pl. 2, fig. 2), generally occurring on the innermost or youngest leaves of the beet. At the beginning this symptom may be confined to a portion of the youngest leaf, but in a few days, in vigorously growing beets, the entire leaf is affected. Sometimes the cleared veinlets and blister-like elevations appear simultaneously on the youngest leaf of beet seedlings (pl. 1, fig. 3). The transparent veinlets sometimes appear on the youngest leaf of beet seedlings within two days after infection with the leafhopper. In older beets in the field, this symptom may develop in from one to two weeks or longer after infection. A diseased beet may retain the transparent venation on the leaves during the entire season and show no other symptom. Late-infected beets suffering from lack of moisture may show the cleared veinlets on the youngest leaves and no other symptom.

Protuberances on Leaves.—Another reliable and constant symptom of curly top is the roughened appearance of the lower surface of the leaves, developing usually after the veinlets have become transparent. A closer examination of this roughened condition upon its first appearance reveals numerous small elevations on the veins resembling tiny warts (pl. 3, figs. 1, 2). As the disease progresses, nipple-like papillae and knot-like swellings (pl. 3, fig. 3) resembling galls develop here and there on the distorted veins. The diseased leaves are dark, dull green in color, thick, crisp, and brittle.

Exudation from Leaves.—When a large number of curly-top beets are examined in the field, an occasional plant may show a few drops of clear viscid liquid exuding from the petioles, mid-rib, or veins on the lower surface of the leaves. Later this liquid becomes black (pl. 3, fig. 4) and sticky, and upon drying forms a brown crust. This syrupy substance often oozes out of many diseased beets after the first irrigation, and attracts enormous numbers of insects which feed upon the sweet drops of beet juice.

Yellowing.—When curly-top beets are irrigated, they sometimes show a temporary improvement, but later the leaves often turn yellow. It is not to be inferred, however, that the yellowing of the foliage occurs only after the fields have been irrigated; the leaves of diseased beets, especially young plants, will turn yellow without irrigation.

Fig. 3. Cross and longitudinal sections of beets affected with curly top. The transverse sections show black concentric rings alternating with light areas. The longitudinal sections show the dark discolorations extending lengthwise through the beet.

Hairy Roots.—When a badly diseased beet is pulled from loose soil, particles of dirt sometimes cling to the rootlets and shake off with difficulty. It is evident that there is an increase in the number of rootlets, a condition which has been described as "hairy root" or "woolly root" or "whiskered beets." In harder soil these roots often tear off when the beet is pulled.

Darkened Rings in Beet Root.—A cross section of a diseased beet often shows black concentric rings which alternate with light areas (fig. 3). A longitudinal section shows the dark discoloration extending lengthwise through the beet.

Beta maritima

Brandes and Klaphaak[1] have introduced seeds from *Beta maritima* and other wild species of *Beta* and propose to cross the primitive with the cultivated beets to ascertain if strains resistant to curly top and other diseases can be developed. *B. maritima* was naturally infected with curly top at Spreckels, California, during the 1925 outbreak of the beet leafhopper. The sugar beet (*Beta vulgaris*) is presumably a derivation of *B. maritima* indigenous to the Mediterranean regions of Europe.

Mangel wurzel or stock beet (Beta vulgaris)

Mangel wurzel or stock beets planted during April at Berkeley were found to be naturally infected during the serious outbreak of the beet leafhopper in 1925. The same varieties planted on the University Farm at Davis were so badly affected with curly top that it was impossible to make a comparative yield test of the two plantings.

The following varieties were naturally infected with curly top: Giant Yellow, Golden Tankard, Half Sugar, Mammoth Long Red, Red Eckendorf, Yellow Eckendorf, and Sludstrup. The reliable foliage symptoms of curly top on mangel wurzel or stock beets are similar to those on the sugar beet.

Nymphs in all stages of development were found on the naturally infected varieties of mangel wurzel or stock beets, and in all probability, the life history was completed on these food plants.

Garden, table, or red beet (Beta vulgaris)

All varieties of garden beets grown in California are naturally infected with curly top. During a severe outbreak of curly top, late-planted garden beets grown in the interior regions of the state are often badly stunted. The foliage symptoms of curly top on garden beets are similar to those on the sugar beet.

Swiss chard (Beta vulgaris cicla)

Swiss chard has been found to be naturally infected with curly top in many localities of California. This plant was badly diseased in the vegetable garden of the Spreckels ranch near King City during 1926 when no general outbreak of the beet leafhopper occurred in the state.

The varieties experimentally infected are Giant Lucullus, Improved Silver, and Large Ribbed White. The reliable foliage symptoms of curly top in Swiss chard (fig. 4) are similar to those in the sugar beet.

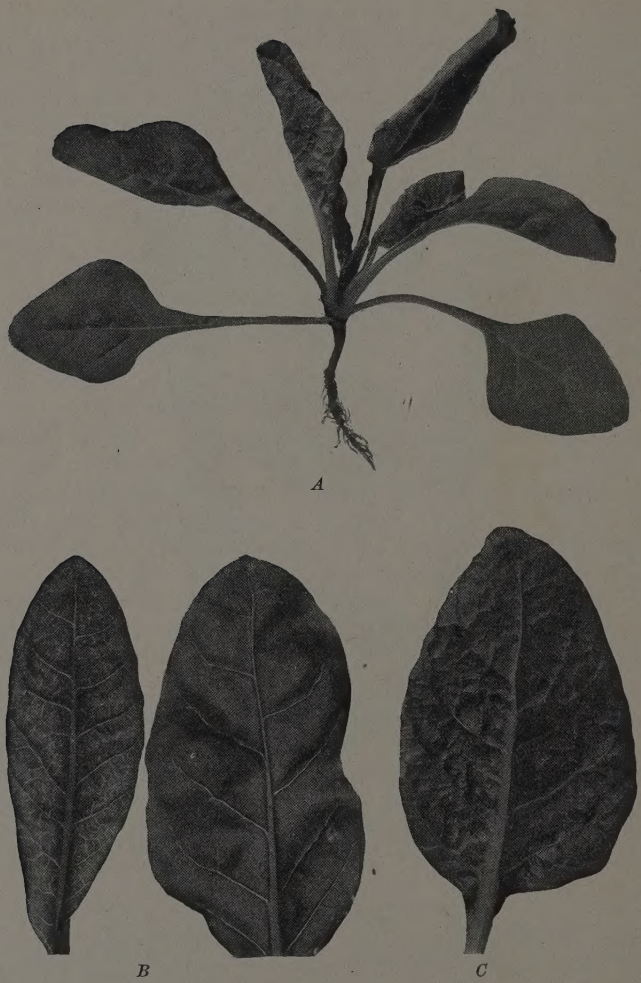
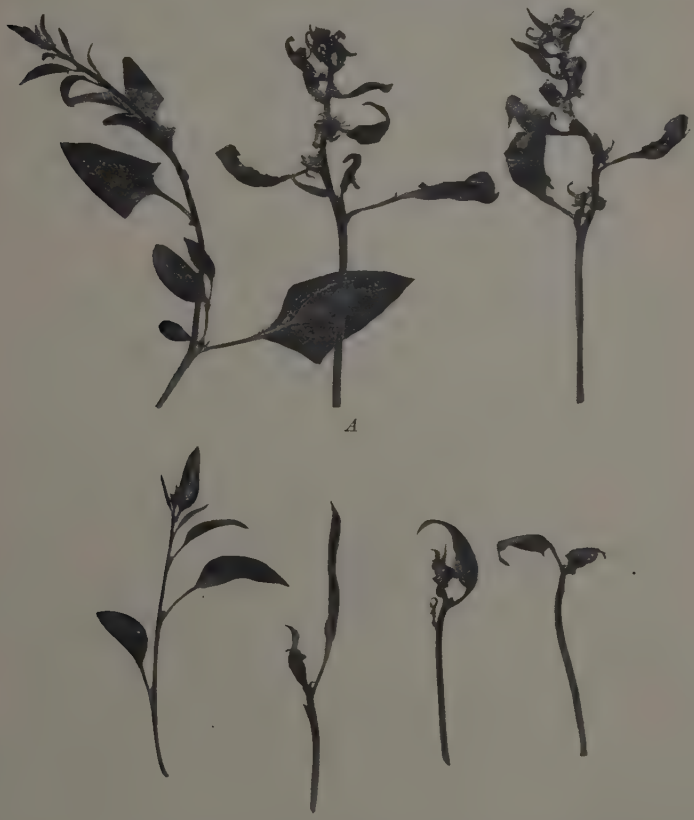


Fig. 4. Swiss chard (*Beta vulgaris cicla*): *A*, plant naturally infected with curly top, showing protuberances on inward-curled leaves (King City, Salinas Valley, September 7, 1926). *B*, left, transparent venation; right, normal venation of healthy leaf. *C*, protuberances on lower surface of leaf affected with curly top.

SPINACH (SPINACIA OLERACEA)

During the 1919 outbreak of the beet leafhopper, spinach grown in the San Joaquin Valley was found to be naturally infected with curly top. In 1925 it was demonstrated that spinach was infected



A

B

Fig. 5. Prickly Seeded spinach (*Spinacia oleracea*): *A*, left, healthy plant used as a check or control on which non-infective beet leafhoppers fed; center and right, plants infected with curly top showing inward-curled leaves. *B*, right, portion of healthy check or control plant; portions of three other plants showing rolled, inward-curled and outward-cupped leaves respectively.

with the disease in the Sacramento Valley. One crop of spinach grown on the University Farm at Davis turned yellow and died. An examination of another planting of Bloomsdale Savoy spinach showed that the beet leafhopper was present but scarce on September 23.

Nine spinach plants in different stages of disease were selected, the leaves of two of which were yellow. Non-infected leafhoppers transmitted curly top from seven plants, including the two yellow plants, to beet seedlings. The bugs failed to transmit the disease from two diseased spinach plants to beets, indicating that the spinach may have suffered also from some other trouble. During 1926 spinach was found to be naturally infected with curly top in the Santa Clara Valley.

The following varieties were experimentally infected with curly top: Bloomsdale Savoy, Long Standing, Round Summer, Prickly Seeded, New Zealand, and Virginia Savoy. The youngest leaves of these varieties showed a clearing or transparency of the minute veins,

Fig. 6. Virginia Savoy spinach (*Spinacia oleracea*) showing youngest leaves rolled toward petioles.

but this symptom is often difficult to distinguish from the normal venation. The leaves may develop an inward curl (fig. 5*A*) or roll (fig. 5*B*), as in Prickly Seeded spinach, or an outward curl or roll toward the petiole (fig. 6), as in Virginia Savoy spinach. Later the young plants turned yellow and died as they do in the field.

LIFE HISTORY OF BEET LEAFHOPPER ON CULTIVATED CHENOPODS

Nymphs which hatched from eggs deposited in the following varieties of cultivated plants of the Chenopodiaceae completed their life cycle on these host plants in the greenhouse: sugar beet; *Beta maritima;* garden, table, or red beets; Giant Lucullus, Improved

Silver, and Large Ribbed White Swiss chard; Bloomsdale Savoy, Long Standing, Round Summer, Prickly Seeded, New Zealand, and Virginia Savoy spinach.

WEEDS AND SHRUBS OF THE CHENOPODIACEAE

The following weeds were found to be naturally infected with curly top: bractscale (*Atriplex bracteosa*); redscale, or red orache (*A. rosea*); silverscale, or fog weed (*A. argentea expansa*); and spearscale, or spear orache (*A. patula hastata*); *Chenopodium leptophyllum*; nettle-leaf goosefoot (*C. murale*); Mexican tea (*C. ambrosioides*); and Russian thistle (*Salsola kali tenuifolia*).

The following weeds and shrubs were experimentally infected with curly top: arrowscale (*Atriplex phyllostegia*); *A. tularensis*; bractscale (*A. bracteosa*); brittlescale (*A. parishi*); crownscale (*A. coronata*); heartscale (*A. cordulata*); redscale, or red orache (*A. rosea*); silverscale, or fog weed (*A. argentea expansa*); and spearscale (*A. patula hastata*); Australian saltbush or fleshscale (*A. semibaccata*); ballscale (*A. fruticulosa*); and quail brush or lenscale (*A. lentiformis*); *Chenopodium leptophyllum;* lamb's quarters (*C. album*); nettle-leaf goosefoot (*C. murale*); Mexican tea (*C. ambrosioides*); and soap plant (*C. californicum*); *Nitrophilo occidentalis*; and Russian thistle (*Salsalo kali tenuifolia*).

The following perennial saltbushes were found to be non-susceptible to curly top: cattle spinach or allscale (*Atriplex polycarpa*) and spinescale (*A. spinifera*).

Recovery from Disease.—*Chenopodium leptophyllum* growing in beet fields in the San Joaquin Valley was occasionally observed with an apparently healthy branch growing from a stunted plant with yellow curled leaves (fig. 7*B*), a phenomenon which may be associated with recovery from the disease.

Longevity of Virus in Perennials.—The longevity of the virus was determined in Mexican tea (*Chenopodium ambrosioides*), a perennial, which was tested and shown to be naturally infected during 1925. Four plants were kept in insect-proof chambers in the greenhouse for one year and during 1926 non-infective beet leafhoppers repeatedly transmitted curly top from the four plants to beet seedlings. On the other hand, quail brush or lenscale (*Atriplex lentiformis*) was experimentally infected with curly top, but one year later non-infective beet leafhoppers failed to transmit the disease from any of the eight plants tested. The eight plants were then reinfected and curly top was again transmitted from two of the quail brush to sugar beets.

Resistant Weeds.—Weeds often show a high degree of resistance to curly top, in fact, some individuals of a species are immune to the disease. Thirty Australian saltbushes (*Atriplex semibaccata*) grown from seeds were repeatedly inoculated with different lots of infective beet leafhoppers, but it was impossible to infect twenty-seven plants.

A *B*

Fig. 7. *Chenopodium leptophyllum: A*, healthy field check or control plant from which non-infective beet leafhoppers failed to transmit curly top to sugar beets. *B*, plant naturally infected with curly top, showing curled leaves on one branch and normal leaves on an apparently healthy stem (Manteca beet field, San Joaquin Valley, July 21, 1925).

The details concerning the methods used with the three infected plants are worthy of mention. Non-infective males transmitted curly top from the first infected plant to one beet seedling, but another beet failed to develop the disease. One lot of non-infective males communicated curly top from the second infected plant to a beet, but another lot of non-infective males allowed to feed on the Australian

saltbush twenty-three days later failed to transmit the disease. The disease, however, was transmitted from the third infected plant by two lots of non-infective males in tests conducted exactly as in the case of the second Australian saltbush.

Cattle spinach or allscale (*Atriplex polycarpa*) and spinescale (*A. spinifera*) are listed as non-susceptible to curly top, but more tests are necessary before it is definitely established that these plants are immune from the disease.

Natural Breeding Plants of Beet Leafhopper.—The beet leafhopper has been bred from eggs deposited in all the weeds listed, except *Atriplex tularensis,* quail brush or lenscale (*A. lentiformis*), cattle spinach or allscale (*A. polycarpa*) and soap plant (*Chenopodium californicum*). The plants upon which leafhoppers were collected were removed with the root system from the field and the nymphs which hatched were reared to the adult stage. It is evident that the eggs were deposited in the weeds under natural conditions and by this method the females were not forced to oviposit in the plants.

One condition greatly favoring an increase of the beet leafhopper in the San Joaquin Valley is the abundance of the breeding plants in the cultivated areas. The plants upon which enormous numbers of nymphs and adults are taken in the field are representatives of the goosefoot or saltbush family (Chenopodiaceae). After the flights of the adults from the plains and foothills into the cultivated regions cease in the San Joaquin Valley during a severe outbreak of the pest, the insects are far more abundant on weeds of the Chenopodiaceae and closely related families than on sugar beets. In the Salinas Valley the most favorable weeds are not so abundant and the multiplication of the hoppers occurs chiefly on the beets.

LEGUMINOSAE, PEA FAMILY

BEANS (PHASEOLUS VULGARIS AND P. LUNATUS)

Destructiveness of Curly Top to Beans in Idaho.—During the serious outbreak of the beet leafhopper in Idaho in 1924, a disastrous epidemic disease of beans occurred in Twin Falls County. Carsner[3, 4] came to the conclusion that the beet leafhopper may have transmitted curly top to beans, although he did not see the disease in the field. He demonstrated, however, that seven varieties of beans commonly grown in Twin Falls County were susceptible to curly top, using the method previously described. The fact that the seven varieties were sus-

ceptible to curly top by inoculating the plants with infective leafhoppers does not prove that any of the varieties were infected with the disease in the field.

Injury in California.—A survey of curly-top infection of field beans was made in the Salinas, San Joaquin, and Sacramento valleys of California during the severe outbreak of the disease in 1925. In the interior regions of the Salinas Valley, Small White beans (*Phaseolus vulgaris*) were seriosly affected with the disease. In a bean field consisting of 481.5 acres on Ranch No. 3 of the Spreckels Sugar Company, near King City, the percentage of curly top was determined in two adjacent fields containing 30.4 and 46.9 acres respectively. The details concerning the dates of planting and plowing under of sugar beets, dates of planting Small White beans, and the percentage of curly top follows.

Field A (30.4 acres)	Field B (49.6 acres)
Feb. 26, beets planted.	Feb. 5, beets planted.
June 11, beets replanted.	June 6, beets plowed under.
July 1, beets plowed under.	June 8, beans planted.
July 3, beans planted.	August 20, beans, 63 per cent curly top.
August 20, beans, 15 per cent curly top.	

The average yield of the 481.5 acres was 4.84 sacks to the acre, but no separate record was taken of fields A and B. Field B was not planted early enough to mature in time to make a full crop. The average yield of field beans, except limas, in California from 1920 to 1924 was 7.7 sacks to the acre. The reduction in the average yield of 2.86 sacks to the acre can to a large extent be attributed to curly top, although minor bean troubles may also have been a factor.

Relation of Spring Flights to Curly-Top Appearance in Bean Fields.—Small White beans were not infected with curly top during the large spring flights which occurred on March 24 to 26, and April 12 to 14, in the Salinas Valley, since the beans were not planted in the two fields until June 8 and July 3. A partial second brood developed on the foothills of the Salinas Valley and the hoppers were still present on the hills on June 5. Some of the second brood adults may have invaded the bean fields.

Relation of Spring Fights to Dates of Planting Beans.—Beans were planted from April 25 to May 1, 1925, on the Spreckels ranches in the Salinas Valley. It is evident that these plantings also escaped the large spring flights of the beet leafhopper.

Flights.—Associated with Plowing Under of Sugar Beets.—It appears probable that after the beets were plowed under on July 1, in field A, the beet leafhoppers flew into the bean fields planted on June 8, in the adjacent field B. From January 4 to February 26, 3,000 acres of beets were planted on this ranch; 2,330 acres were plowed under after curly top developed; 192 acres were replanted from June 6 to 13, and again plowed under in July, forcing the bugs to seek other food plants.

Flights Associated with Harvesting Sugar Beets in the Sacramento Valley.—During the harvesting of the sugar beets in the Sacramento Valley, a number of bean fields were examined in the vicinity of beet fields, and enormous numbers of leafhoppers were found on different varieties of beans. The beans were nearing the ripening period, and curly top probably did not seriously reduce the yield. During 1926 a field of Henderson Bush Limas was swarming with the pest after the beets in an adjacent field had been harvested. A number of plants were tested by the simple method previously described and found to be naturally infected with curly top.

Small Whites, an Unfavorable Host Plant of Beet Leafhoppers.—Small Whites removed from the field near the ripening period proved to be unfavorable food and breeding plants for the beet leafhoppers. The longevity of the adults varied from seven to seventeen days in captivity on this variety of bean, but under natural conditions, they could feed on favorable weeds growing in bean fields. By shaking many Small White bean plants in the two fields a nymph would hop to the ground on very rare occasions, but these may have crawled on the plants from weeds. Nymphs which hatched from eggs deposited in Small Whites failed to acquire the winged stage.

Varieties Naturally Infected.—An examination of other varieties of beans grown in the interior regions of the Salinas Valley such as Bountiful, Cranberry, Kentucky Wonder, and White-Seeded Kentucky Wonder, all classified as *Phaseolus vulgaris,* showed that from 1 to 5 per cent were infected with curly top. The percentage of curly top of Henderson Bush Lima (*P. lunatus sierra*) could not be determined, as no typical foliage symptoms could be detected. Stunted plants with the younger leaves dwarfed and puckered were tested and found to be naturally infected with the disease. These varieites of beans were not replanted from beets to beans, nor were any of these bean fields in the immediate vicinity of beet fields that had been plowed under. The variety Cranberry was found to be infected with curly top in the fog belt at Spreckels.

In the Sacramento Valley the Long Red Kidney bean growing in the vicinity of beet fields that had been harvested was found to be naturally infected with curly top. Foliage symptoms resembling bean curly top were apparently caused by a stem and root rot. A variety of bean known as Stringless Green Pod grown at the University Farm at Davis was also found to be infected with curly top.

Stunted pink beans have not been found to be naturally infected with curly top up to the present time in the Salinas, San Joaquin, and Sacramento valleys. Pink beans in the vicinity of beet fields which had recently been harvested were swarming with the beet leafhopper but non-infective males failed to transmit curly top from this variety of bean to beets.

Field Checks.—Cross inoculations with non-infective males feeding on different varieties of apparently healthy field and garden beans removed from the field as a check failed to transmit curly top to sugar beets.

Experimentally Infected Varieties.—The following varieties of field beans grown in California were experimentally infected with curly top: Bayo, Blue Pod, Cranberry, Lady Washington, Pink, Red Kidney, Red Mexican, Small White, and Spotted Red Mexican, all classified as *P. vulgaris;* also the following varieties of limas (*P. lunatus*): Burpee's Bush, Fordhook Bush, Lewis, and Baby Lima or Henderson Bush. The following varieties of garden beans were tested and found to be susceptible to curly top: Bountiful, Early Refugee, Golden Wax, Kentucky Wonder Pole, Kentucky Wonder Wax, Prolific Black Wax, Scarlet Runner Pole, Stringless Green Pod, White Crease-back, and White-Seeded Kentucky Wonder.

Symptoms.—A study was made of the development of the symptoms of curly top in the common California varieties of field and garden beans grown from seeds. After the cotyledons pushed through the soil and the first pair of leaves appeared, each variety was inoculated by ten infected beet leafhoppers confined in a cage. If the longevity of the adults was short, repeated lots of ten hoppers were put into the cage until symptoms of curly top appeared. The first symptoms to appear in from one to two weeks with varieties of *Phaseolus vulgaris* were a puckering and an outward cupping of the newly developing leaves, with a clearing or transparency of the minute veins. The youngest leaves were decidedly dwarfed and darker green.

In naturally infected Small Whites the cupping of the three leaflets sometimes continued until each leaf resembled a small green

A

B

Fig. 8. Small White bean (*Phaseolus vulgaris*): A, stunted plant naturally infected with curly top, showing compact dense mass of balled inner leaves. *B*, the same plant with the outer leaves removed and the central mass teased apart, showing the balled leaves formed by an outward cupping of the three leaflets (King City, Salinas Valley, August 19, 1925).

ball (fig. 8*A*). Figure 8*B* shows a plant with the outer leaves removed and the central mass of balled inner leaves teased apart.

The varieties of Limas infected in the greenhouse do not show pronounced foliage symptoms of curly top except dwarfing, puckering, and slight cupping of the youngest leaves. Transparent venation,

Fig. 9. Small White bean (*Phaseolus vulgaris*): three bean pods on the left from a healthy plant; eight dwarfed pods on the right, the only pods found on eight plants naturally infected with curly top (King City, Salinas Valley, October 9, 1925).

a reliable symptom of curly top, was usually absent. An occasional infected Henderson Bush Lima showed faint indications of cleared veinlets on the first pair of true leaves.

An early-infected Small White bean plant usually bears no pods. Eight Small Whites naturally infected with curly top were pulled at random in the field on October 8, and there were only eight dwarfed pods on all of the plants (fig. 9).

Fig. 10. Pink bean (*Phaseolus vulgaris*): *A*, plant showing puckering and cupping of youngest leaves, resembling curly-top symptoms. This plant was repeatedly inoculated with different lots of infective beet leafhoppers but non-infective males failed to transmit curly top to sugar beets after feeding on the inoculated plant. *B*, Pink bean infected with curly top by infective beet leafhoppers, showing puckered and cupped leaves. Non-infective males repeatedly transmitted curly top to sugar beets from this plant during a period of three months. *C*, puckered and cupped leaves of Pink bean infected with curly top. *D*, *E*, puckered and cupped leaves of Pink bean from which the disease was not transmitted.

Races of the Pink Bean Resistant to Curly Top.—Carsner[2] states that Pink beans are non-susceptible to curly top.

Pink beans were repeatedly inoculated with different lots of ten infective adults but only three of thirty-seven plants were susceptible to the disease. Typical symptoms of bean curly top (fig. 10*B*, *C*) developed in the three infected plants; some of the other plants inoculated by infective hoppers showed similar symptoms (fig. 10*A*,

D, E) yet non-infective males failed to transmit the disease from the latter to sugar beets. The youngest leaves of many inoculated plants would show a slight puckering and outward cupping, but a few days later these leaves would be normal. It was assumed that possibly the virus remained active for a short time. Experiments were so conducted that non-infective insects could feed on only the youngest puckered leaves for a period of from two to seven hours or longer under high temperatures, and yet the hoppers failed to transmit the disease to healthy beet seedlings. A later experiment with one of three Pink beans infected with curly top during July, demonstrated

TABLE 1

LONGEVITY OF LAST LIVING MALE AND FEMALE OF TWENTY BEET LEAFHOPPERS ON FIELD BEANS

Variety of Bean	Longevity males *days*	Temperatures			Longevity females *days*	Temperatures		
		Max. °F	Min. °F	Mean °F		Max. °F	Min. °F	Mean °F
Bayo	2–3	102	58	78.9	18	102	58	80.0
Blue Pod	3–4	102	58	79.1	7	102	58	79.2
Cranberry	4	102	58	79.3	12	102	58	79.5
Lady Washington	2–3	102	58	78.9	8	102	58	79.1
Pink	2–5	102	58	79.5	12	102	58	79.5
Red Kidney	2	102	58	78.9	9	102	58	79.3
Red Mexican	3	102	58	79.2	10	104	58	80.1
Small White	4	102	60	79.4	11	102	58	79.4
Spotted Red Mexican	2–4	104	60	81.6	10	104	60	81.6
Henderson Bush Lima	4–5	104	60	80.9	7–14	104	60	79.8
Lewis Lima	2–4	104	60	81.0	9	104	60	81.0

that the virus remained active during August and September, since the disease was repeatedly transmitted to beet seedlings. In all probability, races susceptible to curly top occur in the mixture of races in Pink beans, while some strains are highly resistant or immune.

Longevity of Beet Leafhoppers.—The longevity of male and female beet leafhoppers feeding on field beans under high temperatures of the greenhouse is indicated in table 1. Spring or summer-brood adults were used and not the dark overwintering forms. Ten leafhoppers of each sex were fed on two or more bean plants of each variety and the adult life of the last living male and female is recorded in table 1.

It is evident from table 1 that the females live longer than the males on a bean diet.

Curly-top Transmission from One Plant to Another of the Same Variety.—Non-infective beet leafhoppers transmitted curly top from Small Whites naturally infected in the field to three Small Whites

grown from seeds. Non-infective males also communicated the disease from the three infected Small Whites to beets. Similar results were obtained with naturally infected Henderson Bush Limas.

Curly-Top Transmission from One Variety to Other Varieties.—An experiment similar to the preceding was conducted except that the leafhoppers were transferred from a naturally infected Small White to Kentucky Wonder, Henderson Bush Lima, and Early Refugee beans grown from seeds. All varieties of beans developed curly-top symptoms. Non-infective hoppers also transmitted the disease from the three varieties of beans to beets.

The transmission of curly top from one variety to other plants of the same variety or of different varieties of beans is rarely accomplished by male beet leafhoppers under greenhouse conditions owing to the short life of the males on a bean diet. This may not be the case under natural conditions as the leafhoppers are not limited to a bean diet but can feed on favorable weeds.

COWPEA (VIGNA SINENSIS)

Several fields of Blackeye cowpeas were located in the San Joaquin Valley with no beet fields in the vicinity. An occasional beet leafhopper was captured by sweeping the Blackeyes with an insect net. Stunted plants with yellow leaves were tested and found to be naturally infected with curly top.

The varieties of cowpeas susceptible to experimental inoculation with the disease were Blackeye and Whippoorwill or Speckled. Blackeyes were repeatedly inoculated by different lots of ten infective beet leafhoppers but only four of the ten plants tested were proved to be susceptible to the disease. The two varieties of cowpeas showed no reliable foliage symptoms of curly-top; the infected plants, however, were stunted with the leaves slightly yellow. The longevity of the leafhoppers on the two varieties of cowpeas was as follows

	Males	Females
Blackeye	1–3 days	5–13 days
Whippoorwill	2–5 days	8–12 days

HORSE BEAN (VICIA FABA)

The following varieties of Horse beans were tested and found to be susceptible to curly top: Broad Windsor or Horse bean; Small Windsor or New Zealand Horse bean, and Bell Windsor or Small-seeded Horse bean.

Fig. 11. Youngest leaves of Horse bean (*Vicia faba*), showing inward-curled leaves and blister-like elevations, symptoms of curly top.

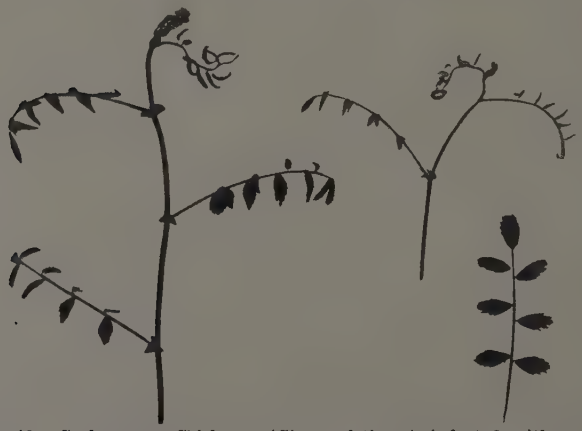


Fig. 12. Garbanzo or Chick-pea (*Cicer arietinum*) infected with curly-top, showing distorted mid-rib of compound leaves and inward-curled leaflets.

The three varieties of Horse beans infected with curly top in the greenhouse showed an inward curl, blister-like elevations and transparent venation of the youngest leaves (fig. 11). Curly top was transmitted from infected Red Kidney and Lady Washington to Broad Windsor or Horse beans, and from the latter to beets. Four males and six females of twenty specimens survived on Broad Windsor or Horse bean for thirty-six days, when the experiment was discontinued.

SPRING VETCH OR TARE (VICIA SATIVA), PURPLE VETCH (V. ATROPURPUREA), AND HAIRY, SAND, OR WINTER VETCH (V. VILLOSA)

Spring, purple, and hairy vetch were experimentally infected with curly top. The youngest leaflets nearest the petioles of the compound leaves were often rolled inward along the mid-rib while the terminal leaflets were malformed. The petiole was sometimes bent downward or the petiole and mid-rib showed a spiral twist.

Fig. 13. Shoots of Hairy Peruvian alfalfa (*Medicago sativa*), showing youngest leaves malformed with blister-like elevations.

GARBANZO OR CHICK-PEA (CICER ARIETINUM)

Garbanzo, or Chick-pea was tested and found to be susceptible to curly top. Marked symptoms of the disease developed. The mid-rib of the youngest compound leaves were distorted and the leaflets were curled inward (fig. 12). In the later stages of the disease, the leaves turned yellow. The males lived from two to five days and the last female died at the end of fourteen days.

HAIRY PERUVIAN ALFALFA (MEDICAGO SATIVA)

Volunteer Hairy Peruvian alfalfa growing in a beet field near Freeport in the Sacramento Valley was found to be naturally infected with curly top during the 1925 outbreak of the beet leafhopper. Enormous numbers of leafhoppers had congregated on the alfalfa. An examination of the adjacent beet fields planted in March, April, and May showed that many of the beets had died from curly top.

The terrific hot spells during the summer had scorched the outer leaves of the beets, leaving a tuft of diseased, thick, leathery leaves. In all probability, the congregation of the hoppers on volunteer alfalfa was associated with unfavorable food from the badly diseased beets.

Fig. 14. Stems of Bur clover (*Medicago hispida*), showing three leaflets folded along the sinuous distorted mid-rib.

Hairy Peruvian alfalfa experimentally infected with curly top showed blister-like elevations, and transparent venation on the youngest dwarfed malformed leaves (fig. 13). Six alfalfa plants experimentally inoculated by the infective beet leafhoppers developed curly-top symptoms, while three plants failed to show foliage indications of the disease. Non-infective males did not transmit the disease from alfalfa without curly-top symptoms to beet seedlings.

The males lived from four to six days on young alfalfa and one of five females remained alive for thirty days, while on old alfalfa the last male died at the end of eighteen days and a few females were still alive at the end of thirty-five days, when the experiment was discontinued.

Fig 15. Stems of White Sweet clover (*Melilotus alba*), showing youngest leaves slightly cupped outward.

CLOVERS

Bur clover (*M. hispida*), valued as dry fodder on the plains and foothills in the long rainless summers of California, was tested and found to be susceptible to curly top. In the diseased condition the three leaflets fold along the sinuous distortions of the mid-rib (fig. 14), and transparent venation is evident on the youngest leaves.

White Sweet clover (*Melilotus alba*) was experimentally infected with curly top. The youngest leaflets were cupped outward along the

mid-rib (fig. 15) with faint indications of transparent venation. The males lived from two to seven days and the females from seven to ten days on White Sweet clover.

The three leaflets of Bitter clover (*Melilotus indica*) were rolled toward the petiole (fig. 16) four days after infection with curly top and transparent venation was plainly visible at the end of ten days.

The symptoms of curly top in White Dutch clover (*Trifolium repens*), Alsike or Swedish clover (*T. hybridum*), Crimson clover

Fig. 16. Tip of plant from Bitter clover (*Melilotus indica*), showing three leaflets rolled toward petiole.

(*T. incarnatum*), Red clover (*T. pratense*), and Mammoth red or Sapling clover (*T. pratense perenne*), experimentally infected, were somewhat similar, the youngest leaflets showed a slight inward roll and transparent venation. In the later stages of the disease the plants turned yellow and died.

LIFE HISTORY OF THE BEET LEAFHOPPER ON LEGUMES

Nymphs which hatched from eggs deposited in the following plants of the Leguminosae completed their life cycle on these host plants in the greenhouse: Broad Windsor or Horse bean; Small Windsor or New Zealand Horse bean; Bell Windsor or Small-seeded Horse bean; Spring vetch; Purple vetch; Hairy Peruvian alfalfa; Bur clover; White Dutch clover; Alsike or Swedish clover, and Red clover.

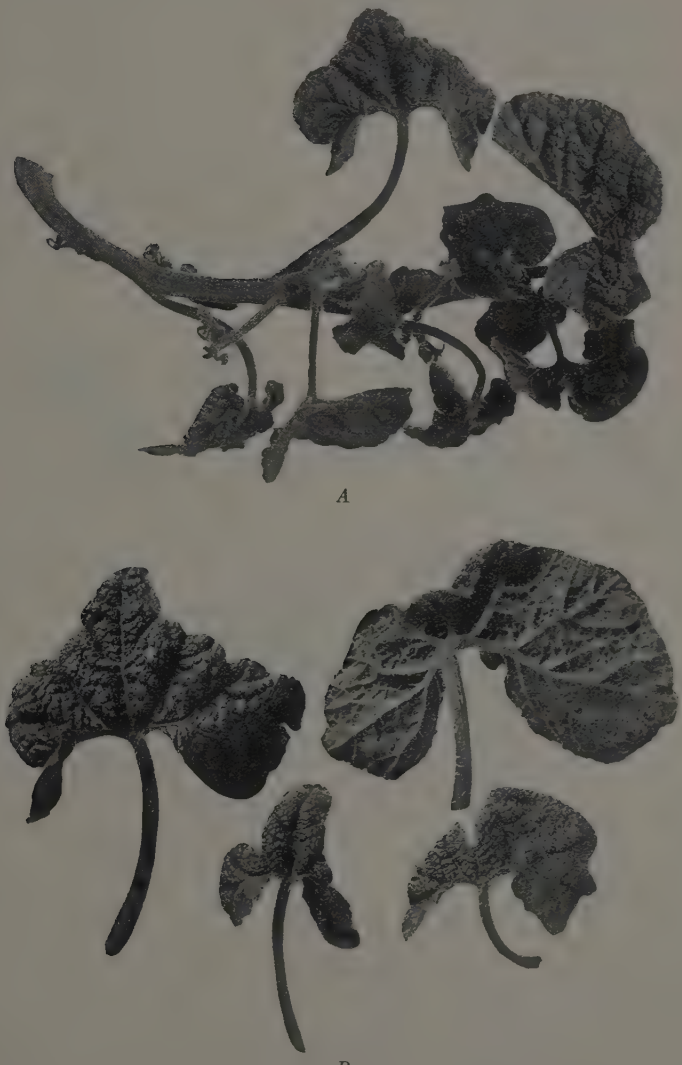


Fig. 17. Delicata squash (*Cucurbita pepo*): *A*, terminal end of runner of naturally infected plant showing puckered and outward-cupped leaves. *B*, malformed, puckered, and cupped leaves removed from the same runner (King City, Salinas Valley, October 9, 1925).

CUCURBITACEAE, GOURD FAMILY

PUMPKIN AND SQUASH (CUCURBITA PEPO, C. MAXIMA, C. MOSCHATA)

Naturally Infected.—The following varieties of pumpkins and squashes growing in the vegetable gardens of the Spreckels ranches near Greenfield and King City in the Salinas Valley were naturally infected with curly top during 1925 and 1926: White Bush Scallop, Summer Crookneck, and Delicata (*Cucurbita pepo*) (fig. 17); Chicago

Fig. 18. Terminal shoots of two plants of Summer Crookneck squash (*Cucurbita pepo*) infected with curly top and of healthy check squash. The cupped leaves are almost globular in shape. Inset shows a flower with calyx but without corolla.

Warted Hubbard (*C. maxima*); Winter Crookneck and Banana (*C. moschata*).

Susceptible Varieties.—The varieties experimentally infected with curly top are California Field, Connecticut Field, Pie Pumpkin, Small Sugar, White Bush Scallop, Yellow Bush Scallop, Summer Crookneck, Vegetable or Italian Marrow, Italian or Zucchine, Long White Vegetable Marrow, Fordhook, Delicata, and Perfect Gem or Cream (varieties of *Cucurbita pepo*); Chicago Warted Hubbard, Golden Hubbard, True Hubbard, Delicious, Boston Marrow, Morse's Marrow (fig. 19), Banana, and Mammoth King (varieties of *C. maxima*); Large Cheese, Green Striped Cushaw, and Mammoth Golden Cushaw (varieties of *C. moschata*).

Symptoms.—A study was made of the development of the symptoms of curly top in the three species of cucurbits grown from seeds, but a considerable amount of variation occurs with reference to the foliage characters of the disease in the different varieties. As a general rule, the first symptoms to appear were puckering and outward cupping (figs. 17, 18, 19) of the newly developing dwarfed leaves. In some varieties the cupping continued until the leaves were almost globular in shape (fig. 18). Transparent venation was often discernible, sometimes accompanied with mottling of the somewhat older leaves. The dwarfed, cupped leaves and petioles were often dark green, with the stems darker green, compared with healthy plants of

Fig. 19. Morse's Marrow pumpkin (*Cucurbita maxima*), showing stunted branches with extremely dwarfed leaves.

the same age. The flowers of infected plants were often dwarfed and dropped from the plants. The calyx in the larger flowers was present but sometimes no corolla developed (fig. 18, inset).

In some varieties the youngest dwarfed leaves may show a slight cupping or may be normal in shape. Successive stages of discoloration from mottling of the older leaves to a decided yellowing of the youngest leaves occurred in some varieties (pl. 4, figs. 1, 2). The yellow discoloration gradually develops between the lateral veins in the older leaves, while the area in the vicinity of the mid-ribs and lateral veins may retain the green color for a time (pl. 4, fig. 2).

Recovery from Disease.—It has been frequently observed in the field that the terminal ends of some runners of naturally infected pumpkins and squashes may show severe curly top symptoms while other runners may be apparently healthy. Similar observations have

been made with infected pumpkins and squashes grown in the greenhouse. In some cases the disease was transmitted to healthy beets from a shoot showing no symptom on a plant which showed symptoms on the stunted portion, while in others it was not. In the case of Delicata squash (fig. 20) the disease was transmitted to beets from

Fig. 20. Delicata squash (*Cucurbita pepo*), showing recovery from curly top. Lower portion of plant shows dwarfed, puckered, cupped leaves, while the upper shoot shows normal leaves.

the stunted portion of the plant showing puckered, cupped, dwarfed leaves, but was not transmitted from the shoot with normal leaves.

Longevity of Beet Leafhoppers.—The longevity of the last living male and female beet leafhopper on different varieties of the three species of cucurbits grown from seeds is shown in table 2. Spring or summer-brood adults were used and not the dark overwintering specimens.

TABLE 2

LONGEVITY OF LAST LIVING MALE AND FEMALE BEET LEAFHOPPER ON PUMPKINS AND SQUASHES

Variety of Pumpkin or Squash	Longevity of males	Longevity of females
Cucurbita pepo	*days*	*days*
California Field	4–5	9
Connecticut Field	4–5	12
Pie	4	10
Small Sugar	5	19
White Bush Scallop	7	14
Yellow Bush Scallop	6	11
Summer Crookneck	10	15
Vegetable or Italian Marrow	2–4	14
Italian or Zucchine	5	10
Long White Vegetable Marrow	4	12
Fordhook	4–5	39
Delicata	6	37
Perfect Gem or Cream	4	21
Cucurbita maxima		
Chicago Warted Hubbard	9	17
Golden Hubbard	3	13
True Hubbard	8	9
Delicious	2–3	14
Boston Marrow	2–3	13
Morse's Marrow	5–6	10
Banana	2–5	11
Mammoth King	4–6	12
Cucurbita moschata		
Large Cheese	5	7
Green Striped Cushaw	5–6	9
Mammoth Golden Cushaw	4–5	5

The adult life of the last living male and female beet leafhopper on varieties of three species of *Cucurbita* may be summarized as follows:

C. pepo: Longevity of males, 2–10 days; females, 9–39 days.

C. maxima: Longevity of males, 2–9 days; females, 9–17 days.

C. moschata: Longevity of males, 4–6 days; females, 5–9 days.

Curly-Top Transmission from One Plant to Another of the Same Variety.—Curly top was transmitted from all of the varieties experimentally infected to other plants of the same variety and then to beets.

Curly-Top Transmission from One Variety to Other Varieties.—The disease was transmitted from one infected variety to different varieties of pumpkins and squashes and then to beets as follows:

White Bush Scallop to Fordhook to beets.
Yellow Bush Scallop to Early White Bush Scallop to beets.
Summer Crookneck to Delicata to beets.
Vegetable or Italian Marrow to White Bush Scallop to beets.
Italian or Zucchine to Chicago Warted Hubbard to beets.
Fordhook to Banana to beets.
Delicata to White Bush Scallop to beets.
Perfect Gem (Cream) to Summer Crookneck to beets.
Chicago Warted Hubbard to Italian (Zucchine) to beets.
Golden Hubbard to Fordhook to beets.
Golden Hubbard to Yellow Bush Scallop to beets.
True Hubbard to Yellow Bush Scallop to beets.
Delicious to Perfect Gem (Cream) to beets.
Boston Marrow to Golden Hubbard to beets.
Morse's Marrow to Connecticut Field to beets.
Banana to Summer Crookneck to beets.
Banana to Green Striped Cushaw to beets.

Curly-Top Transmission from Pumpkins and Squashes to Other Crop Plants.—The disease was transmitted from infected pumpkins and squashes to other cultivated plants as follows:

White Bush Scallop to Ignacia pepper-tomato to beets.
Banana squash to Novata pepper-tomato to beets.
Banana squash to Virginia Savoy spinach.
Mammoth King pumpkin to Arlington White Spine cucumber to beets.

As in the case of beans, curly top is rarely transmitted from infected pumpkins and squashes to the same variety or to different varieties or to other crops by male beet leafhoppers under greenhouse conditions owing to the short life of the males on the three species of *Cucurbita.* Healthy pumpkins and squashes are not favorable host plants of the leafhopper; it is possible that curly top brings about changes in the plant which are of some biological significance to the insect. The beet leafhopper is a sunshine-loving insect; nevertheless, during extremely hot days in the interior regions of California when small favorable weeds wilt, the adults may seek the shade below the large leaves of cucurbits and infect the plants.

Fig. 21. Watermelon (*Citrullus vulgaris*): *A*, Chilian White Seed showing dwarfed youngest leaves. *B*, Angeleno showing stunted lateral branches with dwarfed leaves. *C, D, E*, Georgia Rattlesnake showing puckered and cupped leaves.

WATERMELON (CITRULLUS VULGARIS)

During 1926 a patch of watermelons near King City in the Salinas Valley was destroyed by curly top. The varieties proved to be naturally infected with the disease were Klondyke and Excell.

The following varieties were experimentally infected with curly top: Angeleno (fig. 21*B*), Chilian, Black-seeded Chilian, White-seeded

Chilian (fig. 21*A*), Florida Favorite, Georgia Rattlesnake (fig. 21*C*, *D*, *E*), Golden Honey, Kleckley's Sweet, Klondyke, Kolb's Gem, and Tom Watson.

The youngest leaves of the terminal shoots of infected watermelons show a slight puckering and outward curling (fig. 21*B*). The youngest leaves are deep green, in contrast with the yellow of the older leaves.

Fig. 22. Klondyke cucumbers (*Cucumis sativus*): left, check or control plant on which five non-infective males fed; right, plant infected with five infective males, showing stunting. The leaves above the cotyledons show different stages of yellowing.

Naturally infected watermelons were stunted and yellow, with dwarfed leaves at the terminal end of the runners.

The longevity of the beet leafhopper on the susceptible varieties listed was as follows: males, 2–11 days; females, 5–19 days.

CITRON (Citrullus vulgaris)

Red Seeded citron was found to be susceptible to curly top. The foliage symptoms were similar to those in watermelons. The longevity of the males was 2–6 days and females 4–10 days.

CUCUMBER (Cucumis sativus)

During 1925 and 1926, the following varieties of cucumbers were demonstrated to be naturally infected with curly top in the Salinas Valley: Early Fortune, Long Green, and a variety either Chicago Pickle or Long Green.

It was shown that the following varieties of cucumbers were susceptible to the disease: Arlington White Spine, Boston Pickling,

Fig. 23. Long Green cucumbers (*Cucumis sativus*) naturally infected with curly top, showing slightly cupped, densely clustered, dwarfed leaves, and malformed fruit (King City, Salinas Valley, October 9, 1925).

Early Cluster, Early Frame, Improved Boston Pickling, Improved Telegraph, Japanese Climbing, Klondyke, Lemon, Long Green, Snow's Pickling, Telegraph Rollinson's English Greenhouse, and White Spine.

Several varieties of cucumbers infected with curly top after the first true leaves developed were stunted. The youngest leaves became deep green in color, while the older leaves turned yellow. The yellowing begins at the margin of the leaf (fig. 22) and progresses between the lateral veins toward the mid-rib with a green area along the veins, and at the base of the leaf. Later the stem often bends near the surface of the soil, and the plant wilts and dies. The leaves at the

terminal ends of the runners of naturally infected cucumbers were dwarfed, sometimes slightly cupped and densely clustered together (fig. 23). The fruit was dwarfed and often malformed (fig. 23)

The last living males lived from 3 to 40 days, and the females from 7 to 55 days, in varieties of cucumbers susceptible to curly top.

GHERKIN (CUCUMIS ANGURIA)

Six of nine gherkins tested were susceptible to curly top, after the plants were repeatedly inoculated with different lots of infective males. One of the six plants developed transparent venation on the

Fig. 24. Leaves of Golden Lined Rocky Ford muskmelon (*Cucumis melo reticulatus*) infected with curly top, showing dwarfing and slight puckering with margins turned down.

youngest leaf, but five plants failed to show reliable symptoms of the disease. The adult life on gherkins was as follows: males, 3–9 days; females, 7–11 days.

MUSKMELON (CUCUMIS MELO RETICULATUS)

During 1925 and 1926, three varieties of muskmelons were found to be naturally infected with curly top in the Salinas Valley as follows: Green Nutmeg, Pollock, and Tip Top.

The varieties of muskmelons found to be susceptible to the disease are: Acme, Banana, Blenheim Orange, Burrell's Gem, Early Hackensack, Gold Lined Rocky Ford, Green Nutmeg, Honey Ball Melon, Montreal Market, Paul Rose, Persian, Pollock, Rocky Ford, Tip Top, and Windsor Castle.

Varieties of muskmelons experimentally infected with curly top showed no reliable symptoms. The dwarfed youngest leaves of the stunted plants were sometimes puckered with margins slightly turned down (fig. 24). In the later stages of the disease the leaves became yellow, which was also the case with naturally infected muskmelons. The flowers were also dwarfed and often became dry before the petals expanded. In extreme cases of dwarfing, the flowers were reduced to small round knobs.

The males lived from two to six days and the females from seven to sixteen days on the susceptible varieties of muskmelons.

CANTALOUPE (Cucumis melo cantalupensis)

Salmon tint cantaloupe was found to be naturally infected with curly top in the Salinas Vally during 1925. The varieties tested and found to be susceptible to the disease were Large Yellow and Salmon Tint. The symptoms of curly top on cantaloupes were similar to those on muskmelons. The longevity of the beat leafhoppers on the susceptible varieties was as follows: males, 1–4 days; females, 4–10 days.

HONEY DEW MELON (Cucumis melo inodorus)

During 1926, Honey Dew melon (Hybrid Cassaba) was proven to be naturally infected with curly top in the Salinas Valley. It was also experimentally infected with the disease in the greenhouse. The symptoms were similar to those of the disease on muskmelons. The males lived from one to four days and the females from three to nine days on Honey Dew melons.

CASSABA (Cucumis melo inodorus)

Golden Beauty and Winter Pineapple were tested and found to be susceptible to curly top. The symptoms of the disease were similar to muskmelon. The adult life on the two susceptible varieties of cassaba was as follows: males, 1–7 days; females, 2–12 days.

LIFE HISTORY OF BEET LEAFHOPPER ON CUCURBITS

Nymphs which hatched from eggs deposited in the following plants of the Cucurbitaceae completed their life cycle on these host plants in the greenhouse: Early White Bush Scallop squash, and Boston Pickling, Improved Telegraph, and White Spine cucumbers.

RECOMMENDATIONS ON PLANTING TIME OF VARIOUS CULTIVATED PLANTS TO AVOID CURLY TOP

If the planting schedule as determined for the sugar beet is made use of with mangel wurzel (stock beets), garden beets, Swiss chard, and spinach, better crops will be harvested.

Planting in Natural Breeding Areas.—The following planting schedule of sugar beets in the San Joaquin Valley and the interior regions of the Salinas Valley, usually insures a marketable crop even if a severe outbreak of beet leafhopper occurs. This schedule is related to the spring and autumn dispersal of the insects in natural breeding areas such as these valleys. The fact that in natural breeding grounds most of the insects leave the cultivated areas and fly to the foothills during the autumn has an important bearing on the time of planting beets. Beets should be planted in December, January, and February in the San Joaquin Valley and interior regions of the Salinas Valley. The spring dispersal from the foothills into the cultivated areas usually occurs in April; in some years flights begin in late March and in other years in May. If late spring rains occur, a partial second brood develops and flights may continue in June. If the foliage of sugar beets covers the rows at the time of the invasion of the pest, a good crop can usually be obtained. Early planting, however, is not always safe in the San Joaquin and upper Salinas valleys, as was evident during 1919, when over one-half of the beet crop was blighted by the overwintering hoppers which remained in the cultivated areas.

Planting in Migratory Breeding Areas.—In the Sacramento Valley the overwintering beet leafhoppers are exterminated in the cultivated areas and on the foothills of the Coast Range. There has never been a case of curly top observed in the early-planted beet fields until after the migratory flights occurred. During 1927 and 1928, beets were planted in November but no curly-top beets were found until after the spring migration began. Early planting from November to the end of February insures a crop in the Sacramento Valley during an outbreak of the pest. *During the serious outbreaks of the leafhopper in 1919 and 1925, beets planted in March and April were destroyed* by curly top. In 1925 it was demonstrated that beets planted after the migratory flights ceased in May made a marketable crop. Small migratory flights into the Saramento Valley sometimes occur in April but the large flight usually takes place in May. *In years between*

outbreaks of the pest, beets planted during March and April in the Delta districts usually make good tonnages. If early planting is practiced year after year in the Sacramento Valley, a marketable product will be harvested; on the other hand, if late planting during March and April is adopted year after year, serious losses will be sustained when large migrations of the pest occur.

Planting in Fog Belts.—In the fog belt planting should be discontinued from March first until after the spring flights cease. In the fog belt of the Salinas Valley late plantings in May and June usually result in a good crop. In 1925, however, the late plantings were badly diseased, owing to the fact that a partial second brood developed on the foothills.

Planting Resistant Beans.—After the outbreak of curly top in Small White beans during 1925, the substitution of Pink beans in the Sacramento and Salinas valleys during 1926 was recommended. A large number of Pink beans with slightly puckered leaves were tested from the two valleys but up to the present time not a single plant was found to be naturally infected with curly top.

SUMMARY

The following field and garden plants of three families have been found to be naturally infected with curly top in California:

Chenopodiaceae, Goosefoot or Saltbush family

Sugar Beet (*Beta vulgaris*).

Beta maritima.

Mangel Wurzel or stock beets (*Beta vulgaris*): Giant Yellow, Golden Tankard, Half Sugar, Mammoth Long Red, Red Eckendorf, Yellow Eckendorf, and Sludstrup.

Garden, table, or red beets (*Beta vulgaris*).

Swiss chard (*Beta vulgaris cicla*).

Spinach (*Spinacia oleracea*): Bloomsdale Savoy.

Leguminosae, Pea family

Field and garden beans: Bountiful, Cranberry, Kentucky Wonder, Long Red Kidney, Small White, Stringless Green Pod, and White-seeded Kentucky Wonder (varieties of *Phaseolus vulgaris*); and Baby Lima, or Henderson Bush (*P. lunatus*).

Blackeye cowpea (*Vigna sinensis*).

Alfalfa (*Medicago sativa*): Hairy Peruvian.

Cucurbitaceae, Gourd family

Pumpkins and squashes: Delicata, Summer Crookneck, and White Bush Scallop (*Cucurbita pepo*); Hubbard and Chicago Warted Hubbard (*C. maxima*); Banana, Yellow Summer Crookneck, and Winter Crookneck (*C. moschata*).

Watermelon (*Citrullus vulgaris*): Klondyke and Excell.

Cucumber (*Cucumis sativus*): Early Fortune, Long Green, and a variety either Chicago Pickle or Long Green.

Muskmelon (*Cucumis melo recticulatus*): Green Nutmeg, Pollock, and Tip Top.

Cantaloupe (*Cucumis melo cantalupensis*): Salmon Tint.

The following varieties of economic plants were experimentally infected with sugar beet curly top:

Chenopodiaceae, Goosefoot or Saltbush family

Swiss chard (*Beta vulgaris cicla*): Giant Lucullus, Improved Silver, and Large Ribbed White.

Spinach (*Spinacia oleracea*): Bloomsdale Savoy, Long Standing, Round Summer, Prickly Seeded, New Zealand, and Virginia Savoy.

Leguminosae, Pea family.

Field beans (*Phaseolus vulgaris*): Bayo, Blue Pod, Cranberry, Lady Washington, Pink, Red Kidney, Red Mexican, Small White, and Spotted Red Mexican.

Limas (*P. lunatus*): Burpee's Bush, Fordhook Bush, Lewis, and Baby Lima or Henderson Bush.

Garden beans: Bountiful, Early Refugee, Golden Wax, Kentucky Wonder Pole, Kentucky Wonder Wax, Prolific Black Wax, Scarlet Runner Pole, Stringless Green Pod, White Creaseback, and White-seeded Kentucky Wonder.

Cowpeas (*Vigna sinensis*): Blackeye and Whippoorwill or Speckled.

Horse beans (*Vicia faba*): Broad Windsor or Horse bean, Small Windsor or New Zealand Horse bean, and Bell Windsor or Small-seeded Horse bean.

Spring vetch (*Vicia sativa*), Purple vetch (*V. atropurpurea*), and Hairy sand or winter vetch (*V. villosa*).

Garbanzo or Chick-pea (*Cicer arietinum*).

Hairy Peruvian alfalfa (*Medicago sativa*).

Bur clover (*M. hispida*), White Sweet clover (*Melilotus alba*), Bitter clover (*M. indica*), White Dutch clover (*Trifolum repens*), Alsike or Swedish clover (*T. hybridum*), Crimson clover (*T. incarnatum*), Red Clover (*T. pratense*), and Mammoth Red or Sapling clover (*T. pratense perenne*).

Curcurbitacea, Gourd family.

Pumpkins and squashes: California Field, Connecticut Field, Pie Pumpkin, Small Sugar, White Bush Scallop, Yellow Bush Scallop, Summer Crookneck, Vegetable or Italian Marrow, Italian or Zucchine, Long White Vegetable Marrow, Fordhook, Delicata and Perfect Gem or Cream (varieties of *Cucurbita pepo*); Chicago Warted Hubbard, Golden Hubbard, True Hubbard, Delicious, Boston Marrow, Morse's Marrow, Banana, and Mammoth King (varieties of *C. maxima*); Large Cheese, Green Striped Cushaw, and Mammoth Golden Cushaw (varieties of *C. moschata*).

Watermelons (*Citrullus vulgaris*): Angeleno, Chilian, Black-seeded Chilian, White-seeded Chilian, Florida Favorite, Georgia Rattlesnake, Golden Honey, Kleckley's Sweet, Klondyke, Kolb's Gem, and Tom Watson.

Citron (*C. vulgaris*): Red Seeded.

Cucumbers (*Cucumis sativus*): Arlington White Spine, Boston Pickling, Early Cluster, Early Frame, Improved Boston Pickling, Improved Telegraph, Japanese Climbing, Klondyke, Lemon, Long Green, Snow's Pickling, Telegraph Rollinson's English Greenhouse, and White Spine.

Gherkin (*C. anguria*).

Muskmelons (*C. melo reticulatus*): Acme, Banana Blenheim Orange, Burrell's Gem, Early Hackensack, Gold Lined Rocky Ford, Green Nutmeg, Honey Ball Melon, Montreal Market, Paul Rose, Persian, Pollock, Rocky Ford, Tip Top, and Windsor Castle.

Cantaloupes (*C. melo cantalupensis*): Large Yellow and Salmon Tint.

Honey Dew melon or Hybrid Cassaba (*C. melo inodorus*).

Cassaba (*C. melo inodorus*): Golden Beauty and Winter Pineapple.

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PLATES 1-4

PLATE 1

Sugar Beet (*Beta vulgaris*)

Fig. 1. Beet leaves showing blister-like elevations.

Fig. 2. Portion of beet leaf showing blister-like elevations magnified.

Fig. 3. Beet leaves showing blister-like elevations and transparent venation.

Fig. 1

Fig. 2

Fig. 3

PLATE 2

Sugar Beet (*Beta vulgaris*)

Fig. 1. Beet leaf showing normal venation.

Fig. 2. Beet leaf showing the transparent network of minute veins usually present on the youngest leaves of curly-top beets.

Fig. 1

Fig. 2

PLATE 3

Sugar Beet (*Beta vulgaris*)

Fig. 1. Leaf from curly-top beet showing small wart-like elevations on the veins, giving the lower surface of the blade a roughened appearance.

Fig. 2. Small wart-like protuberances limited to the lower right side of the beet leaf.

Fig. 3. Leaf from curly-top beet showing nipple-like papillae and knot-like swellings on the distorted veins.

Fig. 4. Leaves from curly-top beet showing black liquid exudation on petioles and veins.

Fig. 1

Fig. 2

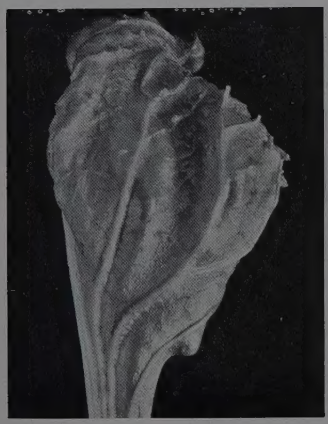

Fig. 3

Fig. 4

PLATE 4

Banana Squash (*Cucurbita maxima*)

Figs. 1, 2. Leaves showing successive stages of discoloration, from mottling of older leaves to a decided yellowing of the youngest leaves.

Fig. 1

Fig. 2